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ON THE NATURE OF SOLAR HIGH-ENERGY PARTICLES

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ON THE NATURE OF SOLAR HIGH-ENERGY PARTICLES

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ABSTRACT

This paper investigates the question of the nature of high-energy particles emitted by the Sun during major chromospheric flares. It is shown on the basis of data analysis of ionospheric observations during the IGY, that protons, as well as heavier particles, such as helium, lithium, carbon, oxygen, sodium and calcium, may be present in the flux. Protons with energies of 350 MeV and less, penetrate the geomagnetic latitudes 62 — 63° N and higher, while heavier particles, with energies of several BeV and less, may penetrate the lower latitudes, through 56.3° N.

COVER-TO-COVER TRANSLATION

There appeared during the last few years informations about the existence of particles with energies of tens and hundreds MeV, emitted from the active regions of the Sun during large chromospheric flares [1 — 5] *. These particles intrude the lower ionosphere at

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* Sometimes they are referred to as "soft cosmic rays".

high geomagnetic latitudes, from the pole of uniform magnetization to $\Phi = 50 - 60°$ N several hours after the commencement of a chromospheric flare, and bring about a complementary ionization of the lower ionosphere layers (particulary the D-layer). Blackouts in the polar cap appear as a result of that (total short-wave absorption), and an increase of galactic radionoises is also observed.* Several cases of anomalous absorption in the polar cap were investigated during the IGY, and certain rules governing its occurrence were ascertained.

The current work is devoted to the investigation of the nature of these high-energy particles according to data of vertical sounding of the ionosphere at 50 station of the Northern hemisphere, situated within the $\Phi = 50 - 90^{\circ}$N range. All the material was compiled in a Table, data on flares being borrowed from [10]. Universal time is used everywhere.

As is well known from the theory of geomagnetic effects of cosmic rays [11], charged particles arrive at the geomagnetic latitude Φ in a vertical direction. Their pulse is not less than

$$P = 14.9\, z \cos^4 \Phi \text{ BeV/s} \qquad (1)$$

where z is the charge of the nucleus. Taking into account that $m = m_0 A$ (where m_0 is the mass of the proton and A — the atomic weight) we have

$$V = 4.9 \cdot 10^{11} \frac{z}{A} \cos^4 \Phi \text{ cm/sec} \qquad (2)$$

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* Reid and Collins 6 called this phenomenon "Type III anomalous absorption".

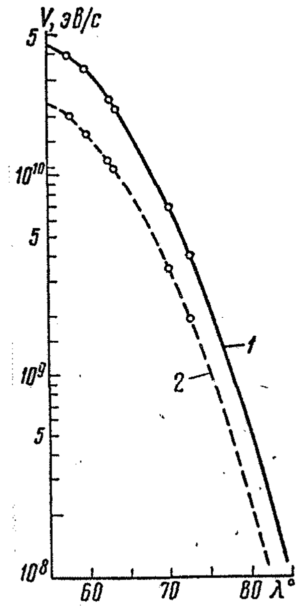
It is shown in [12] that if the effective magnetic moment of the Earth and the magnetic latitude are determined from the Earth magnetic field's components at the given spot, the result agrees better with the experiment than in the assumption of a dipole character of the Earth's magnetic field. The work in reference [13] introduces the idea of the "effective" dipole, constituing a certain angle with the terrestrial dipole. Computed also is the effective latitude $\bar{\lambda}$ by the components at the given spot of the Earth's magnetic field. As a result of this, formulas (1) and (2) take the form (for $\bar{\lambda} > 40^o$):

$$P = 14.9 z \cos^4 \bar{\lambda} \text{ BeV/s} \quad (1a)$$

$$V = 4.9 \cdot 10^{11} \frac{z}{A} \cos^4 \bar{\lambda} \text{ cm/sec} \quad (2a)$$

Year	Chromospheric flare		Anomalous absorption in the polar cap	
	Date & Time	Force	Date and Time	φ_S^o
1957	3.VII, 07 ч. 12 м.	3	3.VII, 09 ч. 00 м.	60,6
	24.VII, 18 » 02 »	3	24.VII, 21 » 00 »	63,0
	8.VIII, 11 » 20 »	3	9.VIII, 23 » 00 »	63,0
	28.VIII, 09 » 13 »	3+	29.VIII, 07 » 00 »	59,6
	31.VIII, 12 » 59 »	3	31.VIII, 14 » 00 »	56,3
	2.IX, 13 » 38 »	3	2.IX, 21 » 00 »	56,3
	11.IX, 2 » 43 »	3	12.IX, 04 » 00 »	63,0
	26.IX, 19 » 07 »	3	26.IX, 21 » 00 »	63,0
	20.X, 16 » 37 »	3+	21.X, 07 » 00 »	59,6
1958	9.II, 21 » 08 »	2+	10.II, 06 » 00 »	59,6
	14.III, 14 » 54 »	3	14.III, 16 » 00 »	63,0
	23.III, 09 » 50 »	3+	25.III, 03 » 00 »	63,0
	6.VI, 05 » 00 »	3	6.VI, 14 » 00 »	68,7
	7.VII, 00 » 39 »	3+	7.VII, 02 » 00 »	56,3
	29.VII, 03 » 03 »	3+	29.VII, 04 » 00 »	63,0
	16.VIII, 04 » 32 »	3+	16.VIII, 06 » 00 »	58,7
	20.VIII, 00 » 31 »	3	21.VIII, 16 » 00 »	59,6
	26.VIII, 00 » 05 »	3	26.VIII, 01 » 00 »	56,3
1959	10.V, 20 » 55 »	3	11.V, 02 » 00 »	56,3
	10.VIII, 02 » 15 »	3	10.VII, 06 » 00 »	56,3
	14.VII, 03 » 19 »	3+	14.VII, 08 » 00 »	56,3
	16.VII, 21 » 18 »	3	16.VII, 23 » 00 »	56,3

The dependence of chargedparticles' velocity upon the effective latitude $\bar{\lambda}$ for the values $z/A = 1$ (curve 1) and $z/A = 0.5$ (curve 2), plotted in the graph, was computed according to formula (2a).



The southern boundaries of the anomalous absorption region are indicated by small circles for several observation cases.

As follows from [14], velocities of the highest of all high-energy particles (first to reach the Earth's atmosphere) are within the $0.4 \div 3.0 \cdot 10^{-10}$ cm/sec range. It may be seen from the Table, that the outer boundary of the region of anomalous absorption in the polar cap did not go below $\Phi = 56.3^{\circ}$ N.

It follows from the analysis of the material, that whenever the anomalous absorption region reached in the Eastern hemisphere the Salekhard station ($\Phi = 56.3^{\circ}$), it was limited in the Western hemisphere by the latitude of Winnipeg ($\Phi = 59.6^{\circ}$). Although the geomagnetic latitudes of these stations differ, the effective latitudes $\bar{\lambda}$ coincide (respectively 62.3 and 62. 5°). A detailed review of ionospheric data shows, that if the anomalous absorption of the IIIrd type is observed in Inverness ($\Phi = 60.6^{\circ}$), it must necessarily be registered in Winnipeg. Although the Inverness geomagnetic latitude is greater than the latter's, its effective latitude ($\bar{\lambda} = 57.7^{\circ}$), is much smaller than than of Winnipeg. Thus, the idea is once more corroborated that the effective latitudes, computed according to [13], convey a better picture of the phenomenon.

Starting from the above data, we may conclude the following on the basis of the graph. The outer boundary of the region of proton intrusion with energies not exceeding 100 — 200 MeV into the lower ionosphere ($z/A = 1$), cannot descend below the latitudes $\bar{\lambda} \sim 64 - 65^{\circ}$ N. Protons, intruding the $\bar{\lambda} \sim 64^{\circ}$ latitude, must have 120 – 130 MeV energies, which agrees well with the results of direct observations [5] at the Loparskaya station ($\bar{\lambda} = 63.7^{\circ}$). The velocity of such protons constitutes $\sim 1.5 \cdot 10^{10}$ cm/sec, which corresponds to the Sun to Earth run time, $\sim$ 12 min. The minimum retardation time of the anomalous absorption relatively to the flare constitutes more or less an hour. Such a great time lag may obviously be explained, either by particle scattering processes in the magnetic inhomogeneities of the interplanetary space (when it is necessary to assume that the length of particle trajectory is 5 times greater than the rectilinear distance), or by the assumption, that particles are trapped by the corpuscular stream, possessing a magnetic field, and then slip away from it.

Heavy particles ($z/A \simeq 0.5$) may penetrate to lower latitudes ($65^{\circ} \geq \bar{\lambda} \geqslant 57^{\circ}7$). The presence in the flux of low-energy cosmic rays of particles heavier than protons, is attested by direct as well as indirect observations (element content in the solar atmosphere, aurora observations, etc...). On the basis of direct experiments particles with $z \geqslant 2 \geqslant 5 \geqslant 15$ were revealed [15 – 17]. These may be helium, lithium, carbon, oxygen. The possibility of presence of sodium and calcium ions was indicated in [1]. The presence of anomalous absorption at such low latitudes as $\bar{\lambda} = 57.7^{\circ}$ and 59.5° (respectively Inverness, and Providence Bay), may be explained by the presence of heavy particles with energies of 2 to 5 BeV [11].

Therefore, protons with energies of 200 MeV and less may figure among high-energy particles emitted by the Sun during major chromospheric flares, as well as heavier particles, with energies of 2 $\div$ 3 BeV and less, that penetrate to lower latitudes through $\bar{\lambda} = 57.7^{\circ}$. These particles may be helium, lithium, carbon, oxygen, sodium and calcium.

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*** E N D ***

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